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# MULTIMEDIA UNIVERSITY

## FINAL EXAMINATION

TRIMESTER 3, 2016/2017

### ENT4066 – NANO ELECTRONICS MATERIALS AND DEVICES (NE)

29 MAY 2017  
9:00 – 11:00 A.M.  
(2 Hours)

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#### INSTRUCTIONS TO STUDENTS

1. This examination paper consists of 5 pages with 4 questions only.
2. Answer all questions.
3. Please print all your answers in the Answer Booklet provided.

## QUESTION 1

- (a) Given that the energy of a free electron in a bulk (3D) semiconductor is :

$$E = \frac{\hbar^2}{2m} (k_x^2 + k_y^2 + k_z^2)$$

- (i) What are the energies if the electron is confined in 2D, 1D and 0D of nanostructures ? [3 marks]  
 (ii) Plot the density of electron states per unit energy and per unit volume for bulk (3D), surface (2D), line (1D) and dot (0D). [4 marks]
- (b) Compare and contrast the electron transport behaviour in conventional and mesoscopic devices in terms of device length ( $L$ ) with respect to the electron mean free path ( $l_e$ ), phase coherence length ( $l_\phi$ ) and Fermi wavelength ( $\lambda_F$ ). [6 marks]
- (c) (i) With aid of a simple diagram, describe the laser generation of nanoparticles (NPs) in liquid. Explain also the effect of photo-fragmentation. [4+1 marks]  
 (ii) Figure Q1(c) shows the optical absorption characteristic of laser-generated silicon NPs,

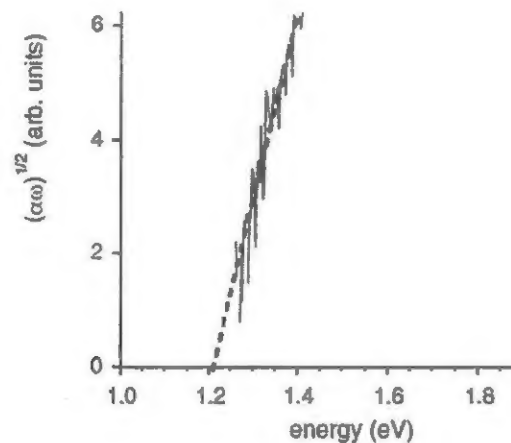


Figure Q1(c)

which is governed by  $\alpha(\hbar\omega) \propto \omega^{-1}(\hbar\omega - E_g)^2$  where  $E_g$  is the bandgap energy. Obtain the bandgap energy,  $E_g$  from Figure Q1(c). [2 marks]

- (iii) The bandgap energy  $E_g$  of Si NPs depends on their diameter (d), given by

$$E_g = E_o + \left( \frac{3.73}{d^{1.39}} \right)$$

where  $E_o = 1.12$  eV. Calculate the average diameter, d. [3 marks]

- (d) Give **FOUR** key issues in the preparation of high-quality nanoparticles. [2 marks]

Continued.....

**QUESTION 2**

- (a) A single wall carbon nanotube can be formed from a two dimension sheet of graphene, with chiral vector : $C = na_1 + ma_2$  where  $a_1$  and  $a_2$  are the graphite lattice vector and  $m, n$  are integer. Show that the diameter of the single wall carbon nanotube formed ( $D$ ) is given by

$$D = \frac{\sqrt{3}a_{cc}\sqrt{(m^2 + n^2 + mn)}}{\pi}$$

where  $a_{cc}$  is the carbon-carbon bond length (1.42 Å). [7 marks]

- (b) (i) Find the diameter and the chiral angle of a single wall carbon nanotube with  $(n, m) = (6, 5)$ . [3 marks]  
(ii) Comment on the structure, chirality and conductivity of the nanotube in b(i). [3 marks]
- (c) Discuss why carbon nanotubes are promising candidate in nanoelectronics; and the challenges faced in realization of carbon nanotubes for electronics. [4 marks]
- (d) Describe the types of bonding found in graphene. How do they affect the properties of graphene? [4 marks]
- (e) With the help of the energy versus wavevector ( $E-k$ ) diagram, explain the distinct carrier transport of graphene as compared to a conventional 2D semiconductor. [4 marks]

Continued.....

## QUESTION 3

- (a) (i) Name the three models of scaling for Field Effect Transistor (FET) based on the factor  $\alpha$ , as shown in Figure Q3(a). Briefly describe the basic ideas and violations in these three scaling rules. [6 marks]

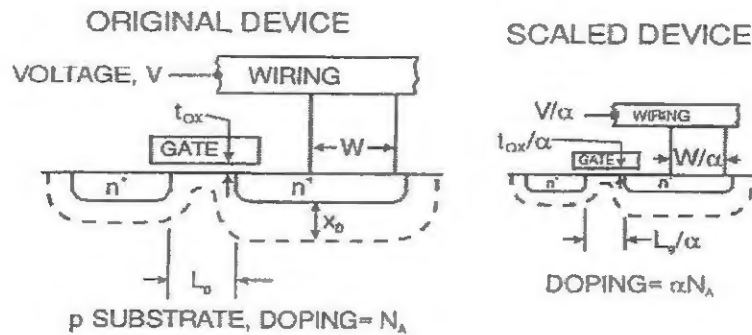


Figure Q3(a)

- (ii) In scaling down the FET, the channel becomes short as compared to its thickness, briefly discuss a few 2-D, or the ratio of channel length-to-thickness effects. [4 marks]

- (b) (i) Figure Q3(b) shows the gate current density as a function of the gate voltage for nano-CMOS, briefly explain the current-voltage characteristic. [3 marks]

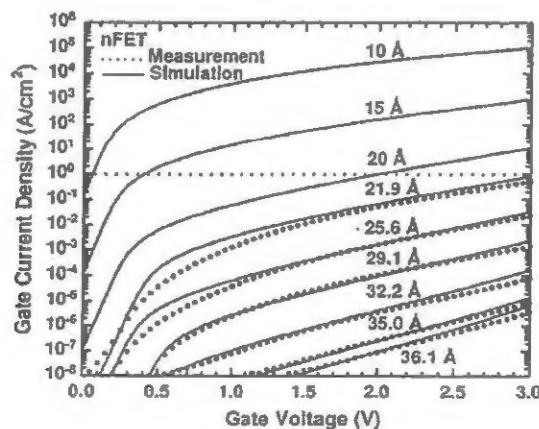


Figure Q3(b)

- (ii) High-k dielectric materials have been considered to replace the conventional  $\text{SiO}_2$  as the gate insulator in nano CMOS. Briefly describe the requirements for choice of high-k dielectric. Name one successful gate-insulation material and sketch its integration scheme. [6 marks]

- (c) Comment on the *floating body effects* (FBEs) in partially-depleted (PD) and fully-depleted (FD) silicon-on-insulators (SOIs) respectively. [6 marks]

Continued.....

**QUESTION 4**

- (a) Electrical conductivity in bulk metals is continuous because there are an enormous number of electronic states in the conduction band of metals, but this is changed at nanoscale.
- (i) With simple diagrams compare the current-voltage characteristic of a normal capacitor and a quantum-dot capacitor charging. [2 marks]
- (ii) What is Coulomb blockade? [2 marks]
- (iii) The capacitance of a nano-sized island used in a single-electron transistor (SET) is given by  $C=2\pi\epsilon\epsilon_0d$ , where  $d$  (12 nm) is the diameter of island,  $\epsilon=4$  and  $\epsilon_0 = 8.85\times10^{-12}$  F/m. Calculate the temperature limit for SET effect. Given that Boltzmann's constant is  $1.38066\times10^{-23}$  J/K. [4 marks]
- (b) Design a Coulomb-blockade, gate-controlled single-electron transition using the silicon-on-insulator substrate. [4 marks]
- The drain and gate capacitors are given by  $C_1 = 1.293\times10^{-17}$  F and  $C_G = 1.724\times10^{-18}$  F. If the temperature  $T$  is close to zero and a gate voltage  $V_G = 0$  is applied, what is the value that  $V_{DS}$  must exceed to overcome the Coulomb blockade ? [3 marks]
- (c) (i) With aid of simple energy band diagrams, explain the operating principle of a double-barrier resonant-tunneling device, in particular how does it differs from conventional tunnelling. [4 marks]
- (ii) Design a resonant tunnelling device made from a double AlGaAs barrier, indicate how the energy-band structure for enabling a resonant tunnelling device. [4 marks]
- (iii) Name and describe an application for resonant tunnelling diode. [2 marks]

**End of Paper**